NASA TECH BRIEF

Welding, Bonding, and Sealing of Refractory Metals by Vapor Deposition

The problem:

To weld, bond, or seal refractory metals without weakening or changing the structure of the base metals. Other welding methods, like the electron beam process, raise the temperature of the base metal near the melting point, resulting in an enlarged grain size that weakens the base metal in the weld area.

The solution:

A plating process in which a metal halide compound in the vapor phase is decomposed strategically to deposit filler metal on the base metal. The bond between base metal and plating material is a true metal-to-metal bond, and is formed at temperatures well below the base metal transition temperature.

How it's done:

Three variations of the vapor plating process may be used, with the same basic principle underlying each variation. The material to be deposited, in the form of a compound in the vapor phase, is impinged on the base metal surface. The conditions at this surface are controlled to cause a chemical reaction within the compound, resulting in the deposit of the desired metal or metallic compound on the base metal and the removal of the reaction products in the form of a vapor. The pure metal or compound deposited on the base metal is a product of the chemical reaction taking place at the base metal surface.

A. Pyrolysis

The base metal is raised to a temperature between 1200° and 2400°C. In a typical process, WCl_6 contacts the heated base metal as a vapor and decomposes because of the high temperature

$$WCl_6 \rightarrow W + 3Cl_2$$

The pure tungsten plates on the base metal, and the reaction products are exhausted in the vapor state.

B. Reduction

The base metal temperature is elevated to a temperature lower than that used in pyrolysis, and the plating compound is mixed with a reducing gas at the base metal surface. A typical reduction reaction is

$$WCl_6 + 3H_2 \rightarrow W + 6HCL$$

with the base metal temperature between 600° and 1200°C. WCl_6 is a low-vapor-pressure solid at room temperature, and must therefore, be raised to 175°C to attain the vapor state. WF_6 is often used in the reduction process because it is a gas at room temperature. Base metal temperatures for WF_6 are between 500° and 750°C.

C. Disproportionation

Plating by disproportionation involves the base metal at one temperature and a second surface (not to be plated) at a different temperature. The following general two-way reaction occurs in this process, where M is the filler metal to be deposited.

$$(b-a)M + aM^{+b} \leftrightarrow bM^{+a}.$$

M exists in two oxidation states, M^{+a} and M^{+b}, with a less than b.

For the plating process, an electronegative element or radical is sought which forms gaseous compounds with the metal (M) in both oxidation states at the desired temperature. The vapor in contact with the two surfaces at different temperatures will contain the two compounds in a proportion intermediate between those defined by the equilibria of the temperatures of the two regions. Therefore, neither is in equilibrium. At the surface which favors (relatively) a

(continued overleaf)

lower oxidation state (the right side of the above equation), the metal is used up. The metal (M) is plated on the other surface.

These vapor plating techniques may be used for overplate bonding and butt or lap welding. In most cases, the base metal is the same as the metal deposited. In an actual butt welding operation, squares of 0.02-inch thick tungsten sheet measuring 0.5 inch by 0.5 inch were mounted on a solid molybdenum-tungsten alloy heater block and preheated by conduction through an electric arc applied to the opposite end of the block from the mounting. The preheat temperature was 700°C, well below tungsten's normal melting point of 3400°C. The area around the weld joint was rendered inert with argon, and tungsten hexafluoride mixed with hydrogen in a ratio of 1 to 5 was applied at an angle across the joint. Pure tungsten was deposited at the joint interface during a 5-minute period. The resultant grain structure within the filler was almost identical to the original specimen structure, and the specimen experienced no degradation, through localized heating, in the area of the joint.

These vapor bonding techniques come very close to fulfilling four criteria of an ideal joint:

(1) Base metal remains unaffected by the process, which operates at temperatures well below its melting point.
(2) Bond of the filler material is metallurgically sound; there is no sharp interface between base metal and filler.
(3) Strength tends to be uniform in the joint area.
(4) Filler material possesses the same grain structure as the base material.

Notes:

1. The vapor plating method has been applied successfully to the overplate bonding of porous tungsten buttons to molybdenum. It has also been used in the formation of a porous tungsten ionizer by plating tungsten to a disc of copper-filled porous tungsten and to a tantalum mandrel.
2. Adhesion tests indicate that tungsten plated on porous tungsten or copper-infiltrated porous tungsten yields a bonding strength greater than the strength of the porous tungsten.
3. Inquiries concerning this innovation may be directed to:

   Technology Utilization Officer
   Lewis Research Center
   21000 Brookpark Road
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   Reference: B67-10232

Patent status:

No patent action is contemplated by NASA.

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